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Journal of Occupational and Environmental Medicine

Volume 44 • Number 4 • April 2002

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ORIGINAL ARTICLES

Lung Cancer and Indoor Exposure to Coal and Biomass in Rural China

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Incomplete combustion of coal in homes has been linked with **lung** cancer in China. We report on a **lung** cancer case-control study in a rural area of China, where many residents live in underground dwellings and burn coal and unprocessed biomass (crop residues, wood, sticks, and twigs) for heating and cooking. We interviewed 846 patients with **lung** cancer (626 men, 220 women; aged 30 to 75 years) diagnosed between 1994 and 1998, and 1740 population-based controls. The odds ratio for **lung** cancer associated with coal use compared with that for biomass in the house of longest residence was 1.29 (95% confidence interval, 1.03 to 1.61), adjusted for smoking and socioeconomic status. The risk for

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lung cancer increased relative to the percentage of time that coal was used over the past 30 years ($P = 0.02$). Our findings suggest that coal may contribute to the risk of **lung** cancer in this rural area of China.

Introduction

Indoor air pollution resulting from the incomplete combustion of coal and unprocessed biomass (crop residues, wood, sticks, and twigs) used to heat homes or cook food is a major public health problem in developing countries. ^{[1] [2] [3]} The smoke generated from incomplete combustion of these fuels contains constituents that have been identified as known or suspected carcinogens in studies of **lung** cancer in China and other countries. ^{[3] [4]} In China, an increased risk of **lung** cancer has been linked to exposure to polycyclic aromatic hydrocarbons from coal smoke ^[5] and benzo(a)pyrene, a known **lung** carcinogen produced from unvented soft, smoky coal used for cooking and heating. ^{[6] [7] [8] [9] [10]}

Most previous indoor air pollution studies in China have been conducted in urban areas, ^{[5] [11] [12] [13] [14] [15] [16] [17] [18] [19] [20]} where high levels of outdoor, industrial air pollution are typical. In contrast, we initiated a **lung** case-control study in a rural area in northwest China. Several sources of pollutants are present in homes in this region, including smoke from coal and unprocessed biomass, tobacco smoke, and radon. However, no major industrial air pollution exists in this area. About half of the residents in the study area of Gansu Province currently live in underground dwellings (or caves) ^[21]; the other half currently live above the ground in houses constructed like "caves," traditional houses, or apartments. The study area provides a unique opportunity to evaluate the effects of exposure to indoor air pollutants in a stable population.

In this report, we evaluated the association between the risk of **lung** cancer and biomass and coal used for heating and cooking. The evaluation of environmental tobacco smoke, ^[22] previous pulmonary diseases, ^[23] cooking oil fumes, ^{23A} and radon^{23B} have been the subjects of earlier reports.

Methods

Study Population

The selection of cases and controls has been described previously. ^[22] Briefly, **lung** cancer cases and their controls were enrolled from two prefectures (Pingliang and Qingyang) in Gansu Province in northwest China. These two prefectures are comprised of 15 counties with a total adult population of 4 million. The study included all **lung** cancer patients diagnosed between January 1994 and April 1998, aged 35 to 70 years old, who were residents of either prefecture at the time of **lung** cancer diagnosis. Patients diagnosed in 1994 and 1995 were enrolled retrospectively, whereas those diagnosed from 1996 to 1998 were enrolled prospectively.

A total of 1209 potentially eligible **lung** cancer cases were ascertained from multiple sources, including local clinics, two prefecture hospitals, one oil field hospital, 15 county hospitals, a network of tuberculosis clinics, and hospitals in the nearby larger cities of Xi'an, Lanzhou, Baoji, and Yinchuan. An expert review panel comprised of five physicians met quarterly to review available diagnostic material for the **lung** cancer cases. The panel excluded 271 (22%) cases because of incorrect diagnoses or lack of supporting evidence. Of the remaining 938 patients, 43 (5%) were not located, 6 (<1%) were outside the age range, and 3 (<1%) had moved from the study area. Thus, a total of 886 (73%) patients (656 men

and 230 women) were eligible for study. Diagnoses of **lung** cancer were based on histologic or cytologic evidence for 353 cases (40%) and on clinical or radiologic evidence for 533 cases (60%) cases. Among this latter group of patients, 414 (78%) were known to have died before the end of the study period, which strongly suggested the validity of the **lung** cancer diagnosis.

Control Selection

We randomly selected 1968 controls from the 1990 population census lists for the two prefectures. Controls were frequency-matched (ratio 2:1) within 5-year age groups in 1995 (estimated midpoint of the study), sex, and prefecture, based on the distribution of **lung** cancer cases determined from a 1991 pilot study. There were 1765 (89.7%) controls who participated in the study, after exclusions due to refusal to participate ($n = 6$), moving out of the study area ($n = 23$), unknown location ($n = 62$), death before 1994 ($n = 73$), unavailability for interview before the end of the study ($n = 35$), or change in status to **lung** cancer patient ($n = 4$).

Data Collection

After informed consent, trained interviewers met with patients and controls in their homes or in the hospital. The interviews consisted of structured questions about residential history, including type of house, amount of time spent in the home during waking and sleeping hours, fuel for heating and cooking, smokiness in rooms during heating and cooking, and type of stove used. Additional questions included measures of income, education, personal and passive smoking, occupation, medical history, family history of cancer, diet, and cooking practices.

Exposure Evaluation

We queried subjects about specific types of fuel and the most frequently used fuel for heating and cooking for each house resided in for at least 2 years over the past 30 years before the reference date (date of diagnosis for patients and date of interview for controls). In addition, we asked the subjects to estimate their average annual coal use. We excluded 5 cases and 11 controls who had gaps of more than 2 years in their occupancy information, 24 cases and 8 controls who had occupancy data for less than 75% of the 30 years before the reference date, and 11 cases and 6 controls who reported fuel use for less than 75% of the prior 30-year interval. We retained 846 (95%) cases and 1740 (99%) controls in the analysis. Subjects typically used either biomass or coal to heat their homes, although many had used both sources sometime in their lives. Few subjects reported using other sources of fuel, such as gas. We calculated the percentage of time coal was used as the most frequent fuel in homes over the past 30 years. For the 131 subjects with gaps in the 30-year interval (maximum gap = 7.5 years, mean gap = 2 years), we imputed a value of 21%, based on the percentage of time that the control houses used coal, as recommended by Weinberg et al. ^[24]

Statistical Methods

We used unconditional, logistic regression to estimate the odd ratios (OR) and 95% confidence intervals (CI) for the association of **lung** cancer and exposure to coal, as represented by the most frequently used fuel and amount of coal in the home lived in the longest, and the percentage of time that coal was used in the 30-year period. A linear trend was calculated treating amount of coal as a continuous variable

using two-sided *P* values. Interaction between variables was determined by a likelihood ratio test. All analyses were adjusted for the matching factors (age, sex, and prefecture), for color television ownership and number of cattle (surrogate measures representing socioeconomic status), and for a measure of risk from tobacco use based on the most heavily exposed category (never; smoked any amount <30 years; smoked 10 or more cigarettes per day, or 500 grams per month of pipe tobacco, for ≥30 years; smoked 20 or more cigarettes per day, or 1 kilogram per month of pipe tobacco, for ≥40 years). A large proportion of the men (92%) and a few women (12%) smoked. Preliminary analyses were adjusted for previous diagnosis of pulmonary tuberculosis, mean radon concentration level (5 to 30 years before the reference date), and housing type, but these variables did not affect the results and were not included in the final models.

Results

Comparison of demographic variables revealed that patients were slightly younger than controls, had more education, owned more color television sets, and had higher incomes.^{[22] [23]} Patients were more likely to have smoked pipes and cigarettes than controls (OR, 1.19; 95% CI, 0.99 to 1.43). Among the patients, 46% were self-responders to the interview, whereas 94% of controls were self-responders. Sixty-two percent of patients and 74% of controls had lived in only one home for 20 years or longer (Table 1). For patients, the greatest number of years lived in one home averaged 23; for controls the greatest number of years in the same home averaged 25. A similar proportion of patients (61%) and controls (65%) reported ever having lived in an underground house.

Table 1. OR and 95% CIs of Selected Residential History Characteristics of Lung Cancer Patients and Controls, Gansu Province, China*

Characteristic	Patients (n = 846)	Controls (n = 1740)	OR†	95% CI
No. of years in home of longest residence‡				
2–19	322	443	1.00	
20–30	520	1291	0.66	0.55–0.82
Type of house of longest residence				
Standard aboveground	349	678	1.00	
Cave-type aboveground	21	37	1.24	0.69–2.15
Underground	433	990	1.13	0.92–1.40
Apartment	38	27	1.37	0.80–2.35
Ever lived underground in past 30 yrs				
No	327	606	1.00	
Yes	513	1128	1.13	0.92–1.39

* OR, odds ratio; CI, confidence interval.

† Excludes four patients and six controls with unknown values for color television or number of cattle.

‡ Adjusted for age at diagnosis (patients) or interview (controls), sex, prefecture, color television ownership, amount of tobacco smoked, and number of cattle owned.

Thirty-three percent of patients and 20% of controls reported using coal as their most frequently used fuel in their house of longest residence. The lung cancer risk for coal compared with biomass in the home of longest residence was increased (OR, 1.29; 95% CI, 1.03 to 1.61), but the trend for lung cancer risk with an increasing amount of coal used was not significant (P for trend = 0.17) (Table 2). When data were restricted to those 32% of patients with known histologic findings, the risk associated with coal use was greater (OR, 1.68; 95% CI, 1.21 to 2.32), with a marginally significant increasing trend for amount of coal used (P = 0.08). Among self-respondents, the risk related to coal use was similar to that for all respondents. We also evaluated the variation in ORs for amount of coal within categories of radon level, prior diagnosis of pulmonary tuberculosis, amount of tobacco smoked, type of house (underground vs aboveground), and smokiness in house during heating. The ORs were unaffected within categories of the first four variables; however, there was a suggestion of a greater trend for risk associated with amount of coal within the categories of self-reported smokiness when a fire was used for heat.

Table 2. OR and 95% CIs of Lung Cancer Associated With Most Frequently Used Fuel in Home of Longest Residence, Case-Control Study, Gansu Province, China*

Type of fuel	Men				Women				Combined†	
	Patients	Controls	OR‡	95% CI	Patients	Controls	OR‡	95% CI	OR‡	95% CI
Biomass	395	1,027	1.00		159	353	1.00		1.00	
Coal	220	251	1.41	1.09–1.82	58	93	1.03	0.66–1.63	1.29	1.03–1.61
Amount of Coal§										
0	243	658	1.00		82	196	1.00		1.00	
I	95	223	1.04	0.77–1.39	51	88	1.48	0.94–2.32	1.18	0.92–1.51
II	148	268	1.00	0.76–1.34	59	104	1.18	0.75–1.88	1.06	0.83–1.34
III	108	121	1.44	1.02–2.04	26	57	0.93	0.52–1.67	1.29	0.96–1.73
			$P = 0.043$				$P = 0.525$		$P = 0.173$	

* OR, odds ratio; CI, confidence interval.

† 10 patients and 10 controls excluded because of other fuel type; four patients and six controls excluded because of other missing information.

‡ Adjusted for age at diagnosis (patients) or interview (controls), sex, prefecture, color television ownership, amount of tobacco smoked, and number of cattle owned.

§ Amount of coal is the estimated annual amount of coal used in the home of longest residence. Tertiles of coal: I = 15–500 kg, II = 501 to 1500 kg, III = 1501 to 7,000 kg.

□ 34 patients and 25 controls excluded because of missing information on amount of coal.

Table 3 shows a trend for increased risk of lung cancer with increasing percentage of time that coal was used most frequently over the past 30 years. The ORs for no coal use, for coal use 0.7% to 56% of the time, and for coal use more than 56% of the time were 1.00, 1.99, and 1.51 (P for trend = 0.024).

Table 3. OR and 95% CIs of Lung Cancer Associated With Percentage of Time Coal Used as Most Frequent Fuel in Past 30 Years, Case-Control Study, Gansu Province, China*

% of Time Coal Used	Men				Women				Combined†	
	Patients	Controls	OR‡	95% CI	Patients	Controls	OR‡	95% CI	OR‡	95% CI
No coal use§	353	982	1.00		125	332	1.00		1.00	
0.7–56	62	78	1.69	1.15–2.47	40	28	2.83	1.60–5.00	1.99	1.46–2.71
57–100	207	226	1.60	1.22–2.10	55	88	1.33	0.83–2.14	1.51	1.20–1.91
			$P = 0.013$				$P = 0.626$		$P = 0.024$	

* OR, odds ratio; CI, confidence interval.

† Four patients and six controls excluded because of unknown number of cattle owned or television ownership.

‡ Adjusted for age, sex, prefecture, television ownership, amount of tobacco smoked, and number of cattle owned.

§ Subjects with no primary coal use were placed in the referent group.

Discussion

Residents in these two rural prefectures in northwest China were exposed to a complex mixture of indoor air pollutants: burning coal, biomass, tobacco smoke, and radon. We detected a modestly elevated risk of lung cancer among residents who burned coal compared with those who burned biomass for cooking and heating, but we did not detect a clear dose-response of increasing risk with increasing amount of coal used in the home of longest residence. The risk of lung cancer increased with the percentage of time that coal was used for heating and cooking in the past 30 years in this study population.

A sub-study we conducted of indoor air pollution in 25 homes in the study area demonstrated high levels of combustion by-products during the cooking and heating activities ^{[25] [26]} over a 12-hour period. Pollutant levels typically spiked when the stoves were in use to prepare meals and when the kang (raised brick sleeping platform) was heated later in the evening. Except for time-integrated measurements of carbon monoxide and mass density of particulate matter smaller than 10 microns (PM 10), mean values for nitrogen dioxide, nitrous acid, and sulfur dioxide did not exceed the US National Ambient Air Quality Standards. The mean values for particle-bound polycyclic aromatic hydrocarbons and PM 10 were higher in houses using coal; however, there were too few houses to draw firm conclusions (Table 4).

Table 4. Mean Values for Real-Time Measurement Data by Type of Fuel Used, (Bituminous) Coal or Firewood, Twigs and Other Biomass, From a Sub-Study of 25 Homes, Gansu, China^{*}

	Coal	Biomass	P [†]
CO ₂ (ppm)	900.8	968.9	0.68
NO (ppm)	0.42	0.46	0.88
NO ₂ (ppm)	0.06	0.05	0.56
SO ₂ (ppm)	0.47	0.59	0.71
PAH (ng/m ³) [‡]	4,897	3,063	0.27
PM 10 (µg/m ³) [§]	2,817	1,030	0.26
Ventilation (air exchanges/hr)	1.39	1.65	0.63

* CO₂, carbon dioxide; NO, nitric oxide; NO₂, nitrogen dioxide; SO₂, sulfur dioxide; PAH, polycyclic aromatic hydrocarbon; PM 10, particulate matter smaller than 10 microns.

† P value for test of homogeneity of means (from a one-way analysis of variance).

‡ Particle-bound PAH.

§ Mass density of PM 10.

In general, previous case-control studies of indoor air pollution in China have focused primarily on female populations and urban areas (Table 5). Most of the results indicated a modest effect of coal burning on lung cancer risk compared with use of wood or gas. Some but not all studies adjusted their analyses for other possible confounding factors, such as age, education, and smoking status. The results from our study are consistent with these studies. ^{[5] [12]} Although we have no information on the contaminants of the coal that was burned for fuel in Gansu Province, most subjects reported using bituminous coal. However, the risks in our study for coal burning are lower than those reported for residents exposed to unvented soft, smoky coal smoke in Xuan Wei, China. ^{[7] [8]}

Table 5. Summary of Lung Cancer Case-Control Studies in China of Exposure to Coal for Heating and Cooking

Reference	Location	Subjects	Results and Comments [*]
^[11]	Nanjing	672 female patients 735 female controls	Relative risks (and 95% CIs) for cooking with coal, gas, and wood as

			usual fuel: 0.9 (0.7–1.3), 1.1 (0.7–1.5), 1.0 (0.6–1.8). No trend in risk for increasing years of coal use.
[8]	Shenyang	729 male patients 520 female patients 1345 controls	ORs for 0, 1–39, 40–49, and 50+ years of kang (coal) use: 1.0, 0.8, 0.9, 1.0 men; 1.0, 2.4, 1.9, 3.4 women ($P < 0.05$). Adjusted for smoking and education.
[12]	Shenyang Harbin	965 female patients 959 female controls	ORs (and 95% CIs) for 0–20, 21–40, and 40+ years of coal stove use: 1.0, 1.2 (1.0–1.6), 1.3 (1.0–1.7); for coal burners, 1.0, 1.2 (1.0–1.6), 1.1 (0.8–1.4); adjusted for age, education, smoking, and study area.
[13]	Guangzhou	92 female patients 224 male patients 92 female controls 224 male controls	ORs (and 95% CIs) for cooking with coal, gas, or wood: 1.00, 0.48 (0.2–1.6), 0.57 (0.1–3.0) for men; 1.00, 0.90 (0.2–3.3), 0.67 (0.04–11) for women.
[14]	Nanjing	83 squamous cell 180 adenocarcinoma 263 controls	ORs (and 95% CIs) for coal stove (heating) for squamous cell: 3.72 (0.9–1.6). Data not given for adenocarcinoma.
[15]	Guangzhou	563 male pairs 229 female pairs (deceased subjects)	Exposure to coal smoke (infrequent vs regular): $P > 0.05$ for both men and women. ORs not presented in article.

[16]	Harbin	120 non-smoking female patients; 120 non-smoking controls	ORs (and 95% CIs) for years of coal use in bedroom: 1–19, 30+ years: 4.46 (1.6–12), 18.8 (3.9–29). For years of heating by coal: 1–24, 25–34 years: 5.81 (1.7–20), 4.70 (1.3–17). Exposure to coal dust 10+ years: 2.66 (1.1–6.5)
[17]	Fuzhou	78 male patients 24 female patients 234 male controls 72 female controls	ORs (and 95% CIs) for air pollution due to indoor coal burning: 14.1, $P = 0.0261$ squamous cell; 6.0, $P = 0.0018$ adenocarcinoma; 7.6 (3.7–15.7) all cell types; adjusted for income and smoking.
[18]	Taiwan	117 female patients 117 female controls	ORs (and 95% CIs) for cooking fuel by cooking age: no cooking, coal, wood, or charcoal: <20 years: 1.0, 0.5 (0.2–1.6), 2.5 (1.3–5.1); 20–40 years: 1.0, 1.1 (0.4–3.0), 2.5 (1.1–5.7); >40 years: 1.0, 1.1 (0.3–8.0), 1.0 (0.2–3.9)
[19]	Shanghai	504 non-smoking female patients 601 non-smoking female controls	ORs (and 95% CIs) for fuel used for cooking (coal, coal+gas, gas): 1.00, 0.92 (0.6–1.4), 0.90 (0.7–1.2); adjusted for age, SES, vitamin C, passive smoking, occupation, and family history of lung cancer.
[20]	Shenyang	72 female patients with adenocarcinoma; 72 female controls	OR (and 95% CI) for exposure to burning coal fumes: 0.97 (0.64–1.48)

[8]	XuanWei	97 patients 97 controls	ORs (and 95% CIs) for exposure to 130, 130–240, 240+ tons of smoky coal; 1.00, 1.48 (0.7–3.0), 3.21 (1.2–9.0); <i>P</i> for trend = 0.01; adjusted for age, gender, and smoking.
Current study	Gansu	220 female patients 450 female controls 626 male patients 1290 male controls	ORs (and 95% CIs) for heating fuel: coal vs biomass in home of longest residence: 1.00, 1.29 (1.0–1.6) male + female. Percent of time coal used in past 30 years (none, 0.7–56%, 57–100%): 1.00, 1.99, 1.51; <i>P</i> = 0.024, adjusted for age, sex, prefecture, smoking, SES.

* CI, confidence interval; OR, odds ratio; SES, socioeconomic status.

Our sub-study of indoor air pollution revealed high ventilation rates, averaging 1.5 air exchanges per hour, followed by a rapid decrease in pollutant concentrations after the cooking or heating activity had concluded. Other studies of housing in developing countries have also noted high ventilation rates when biomass or coal is burned. [27] Although the exchange between indoor and outdoor air is usually high, the pollutant emissions rates for coal and biomass are also high, resulting in high indoor concentrations of pollutants. All of the homes in the study area have always had chimneys (Personal communication, Z. Wang), although many of the underground dwellings vent their stove/kang flue directly next to the cave entry, causing reentry of chimney exhaust into the dwelling through door and vent openings. [26]

The limitations of our study include the absence of air pollution measurements in all homes and the possible misclassification of exposure. We were unable to separate completely the effects of biomass and coal, because many subjects in our study had burned both biomass and coal for heating and cooking at some time in their lives. It is likely that members of the reference group were not “lifelong” biomass users. The contamination of the reference group would diminish the risk associated with coal; however, misclassification of exposure should not have been differential between cases and controls. Although studies have suggested that exposure to wood smoke might induce non-malignant respiratory diseases, [28] no significant association has been reported between exposure to wood smoke and lung cancer. [2] Wood smoke produces larger particle sizes, which are less likely to be deposited in the deep lung and therefore may be less damaging than coal smoke.

Other limitations of our study included next-of-kin interviews and a low percentage of histologically confirmed lung cancer cases. However, the results for self-respondents did not differ materially from the results for all subjects. Moreover, restricting the analyses to cases with histologic findings actually

strengthened the risk for **lung** cancer associated with coal.

Conclusion

In summary, our data suggest a modestly increased risk of **lung** cancer related to coal burning in the home compared with biomass smoke, which increased with an increasing percentage of time that coal was used in the past 30 years.

Acknowledgments

This research was supported by a contract between the National Cancer Institute and the Laboratory of Industrial Hygiene, Beijing, People's Republic of China (NO1-CP-50509) and Westat, Inc (NO2-CP-81121). We wish to acknowledge the contribution of Drs Jiguo Shi, Yuelan Kang, Datong Zhao, Fuhui Du, and Yucheng Wang for the identification of **lung** cancer cases, and the local investigators from Pingliang and Qingyang prefectures and the investigators from the Laboratory of Industrial Hygiene, Beijing, for their assistance with data collection. We also thank Ms Margaret Pacious of WESTAT, Inc, for data management and Mr Eric Berger of IMS for programming support.

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